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ORIGINAL PAPER

In vivo biomechanical comparison of hammering vs drilling of Kirschner wires; a pilot study in rabbits

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Abstract Heat generation due to drilling Kirschner wires (K-wires) into bone can lead to serious complications. Hammering K-wires could be an alternative insertion method because it generates less heat and results in better fixation and a shorter insertion time. There is, however, no in vivo information about insertion time and biomechanics of hammered K-wires. Insertion time was measured when drilling or hammering K-wires into femurs and tibias of 16 rabbits. Four K-wires inserted in one hind limb were used to measure extraction and torque forces directly after insertion ($T = 0$) and four K-wires inserted in the contralateral hind limb were used for the same measurements 4 weeks after insertion ($T = 4$). The insertion time for hammering was significantly shorter compared to drilling. Extraction and torque properties measured at $T = 0$ and $T = 4$ were equal for both techniques. Hammering, however, resulted in more cracks. Based on these results neither of these methods can be identified as a superior technique to insert K-wires in fragile bones.

Keywords Animal · Biomechanics · K-wire · Pneumatic hammer

Introduction

Hand fractures are the second most common fractures after forearm fractures. They account for up to 20% all fractures [7, 14]. K-wire fixation, especially, is the treatment of choice if the forces of the intrinsic and extrinsic tendons prevent adequate splint or cast immobilization [23]. A high-speed drill is the standard tool used to insert K-wires into bone [21]. This percutaneous technique is considered as a simple and quick method that reduces postsurgical swelling and stiffness compared to open reduction and internal fixation [17]. The currently used drill technique, however, can cause human phalanges to reach temperatures of up to 141°C, which can result in serious heat-related complications [1, 2, 18, 26]. If temperatures exceed 47°C for 1 min, osteonecrosis occurs [8–10]. This may cause infection and loosening of pins [1, 2, 18]. Pin-track infections require early removal of the pins, even before consolidation is reached [15]. Pin-track infections occur in up to 18% of the cases, 42% of which finally result in nonunions and even cases of osteomyelitis [4, 12, 13, 16, 23].

Hammering can be an alternative insertion method of K-wires. Hammering has some advantages compared to drilling in vitro, including lower temperatures, better initial fixation, and shorter insertion time [24, 26]. However, to our knowledge, there are no reports of biomechanical aspects of hammered K-wires in vivo. Therefore, in the present study, we compared biomechanics and insertion time of drilled and hammered K-wires.

K-wires were inserted into femurs and tibias of rabbits by drill or pneumatic hammer. Besides insertion time, we measured extraction forces to remove the K-wires and torque forces necessary to turn loose the K-wires directly (t=0) and 4 weeks after surgery (t=4).

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Materials and methods

Sixteen female New Zealand white rabbits (2.94±1.48 kg) were used. They were individually housed on a 12/12-h (light/

dark) cycle and provided with standard diet food and water ad libitum. All animals were housed in the Central Animal Laboratory, Utrecht University, Utrecht, the Netherlands, and received care in compliance with the European Convention Guidelines. Full approval from the Utrecht University Committee for Experiments on Animals was obtained and was in accordance with Dutch laws on experimental animals.

The animals were preanesthetized with a combination of methadone [10 mg/ml at a dose of 2.5–5.0 mg intramuscular (IM)], ventraquil (10 mg/ml at a dose of 2.5–5.0 mg IM), and etomidaat (2 mg/ml at a dose of 2.0–8.0 mg IV). Preoperative X-rays were made to exclude deformities. The rabbits were cuffed and mechanically ventilated with O_2:N_2O (proportion 1:1) and 1% halothane.

During surgery, the rabbit was fixed on an operation device (Fig. 1) that enable positioning of the pneumatic hammer or drill including K-wire in front of the femur or tibia. The insertion force was standardized using 1.5- or 1.0-kg weights for drilling and hammering, respectively.

Hammering was performed with a Lithoclast hammering device [24] (EMS Medical GmbH, Konstanz, Germany). The pressure was standardized at 1.0 Bar. Drilling was performed with a rotary engine set at 1,200 rpm [20].

Methadone was administered (2.0–5.0 mg IV) during surgery. A straight-line skin incision was made on the lateral aspect of the femur extending from just below the anterior inferior spine to the distal femur. Then, a straight-line skin incision was made on the lateral aspect of the tibia extending from just below the joint line proximal to the joint line distally. Dissection was carried out down to the periostium. Trocar tipped K-wires (0.6×70 mm, Synthes, Zeist, the Netherlands) were inserted parallel to each other through the diaphysis of the bone. Four K-wires were inserted using hammering and drilling in one hind limb of each rabbit; two K-wires in the femur and two in the tibia. After penetration of the first cortex, drilling or hammering was stopped as soon as resistance of the second cortex was noticed. K-wires were cut and ends were bent towards the cortex before closure of the wound. X-rays were made to assess K-wire position and condition of the bone. At the end of the procedure, the rabbits received nalbuphine (10 mg/ml at a dose of 1.0–2.0 mg/kg IV) and were housed at the Intensive Care Unit for the rest of the day and night. Surgery was taped on video; after the procedure, we could exactly measure duration of drilling and hammering.

The same surgical procedure was repeated in the second hind limb 28 days later. Immediately after the second procedure, T=0 measurements were performed on the second limb, and T=4 measurements were performed on the first. The rabbits were euthanized by an IV overdose of pentobarbital. With the K-wires in situ, femur and tibia were inspected for fractures. One K-wire was used either for torque or for extraction measurements. The femur and tibia were placed in a bench device, after which the K-wire was extracted with an advanced force Gauge (MECMESIN AFG 1000N). Torque force was measured with a torque apparatus developed by the department of Oral and Maxillofacial Surgery, Prosthodontics and Special Dental Care, Utrecht Medical Center, Utrecht, the Netherlands.

Within-group or between-group differences in the extraction and torque measurements were analyzed by the Bonferroni Multiple Comparisons and Independent t test, respectively. Between-group differences in excluded measurements were analyzed with Fisher's Exact Test. Statistical significance was determined based on $p<0.05$. Data were analyzed using SPSS 12.0.1 for Windows.

Results

X-rays showed no fractures either before or directly after surgery. Eighty-three K-wires were used for measurements. Five rabbits were excluded for further analysis due to femur or tibia fractures within 24 h after surgery. This resulted in the exclusion of 8 directly and 21 indirectly fracture-related measurements (Fig. 2). Additionally, 16 were excluded due

Fig. 1 The operation device used in the study

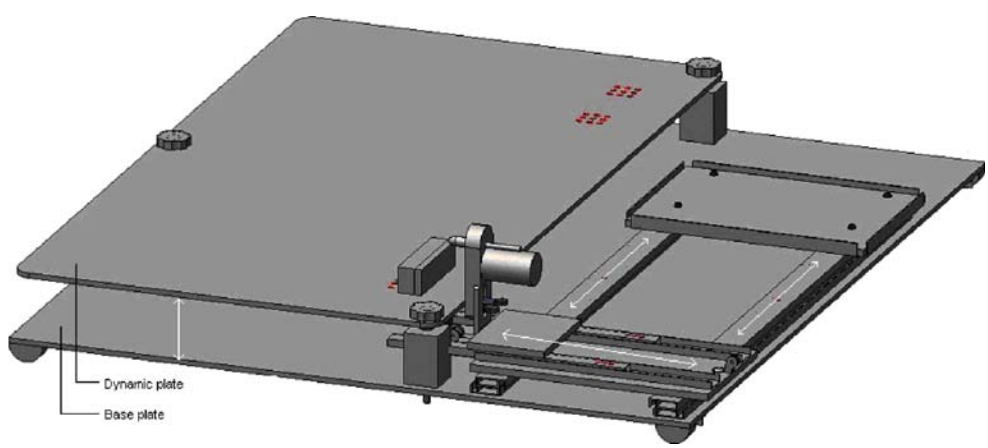

Fig. 2 Broken tibia one day after Kirschner wire insertion

to insufficient penetration of K-wires (n=3) and loose K-wires due to a crack (n=13) (Fig. 3). Hammering resulted in significantly more cracks (p<0.000).

Biomechanical measurements

Biomechanical measurements showed no significant difference for both time points. Extraction forces are presented in Fig. 4a and torque forces in Fig. 4b (Table 1).

Duration

Insertion time was significantly longer for drilling compared to hammering: 142±21 vs 13±1.6 s, respectively (p<0.000).

Discussion

The most important findings of this experiment are that (1) extraction and torque forces of drilled vs hammered inserted K-wires are equal and (2) hammering K-wires results in a significantly shorter insertion time but (3) results in increased occurrence of cracks.

Compared to other reports in the literature, our extraction measurements for drilled K-wires were lower (Table 1). A reason for these lower extraction forces is the use of smaller-diameter K-wires in the present study [20]. This was necessary because bigger-diameter K-wires cause unacceptable bone damage in this model. An additional reason could be the currently used drilling speed, which was higher compared to that used in other published experiments, resulting in lower extraction forces [11, 20]. We choose a drill speed of 1,200 rpm because this is the maximum drill speed used in our clinic.

This is the first experimental study to compare these insertion modalities in vivo. In an earlier report, our study group presented results of in vitro comparisons between drilling and hammering. In vitro, extraction and torque forces were more than doubled when the hammering technique was used instead of the drilling technique. Surprisingly, results of the present study show that, in

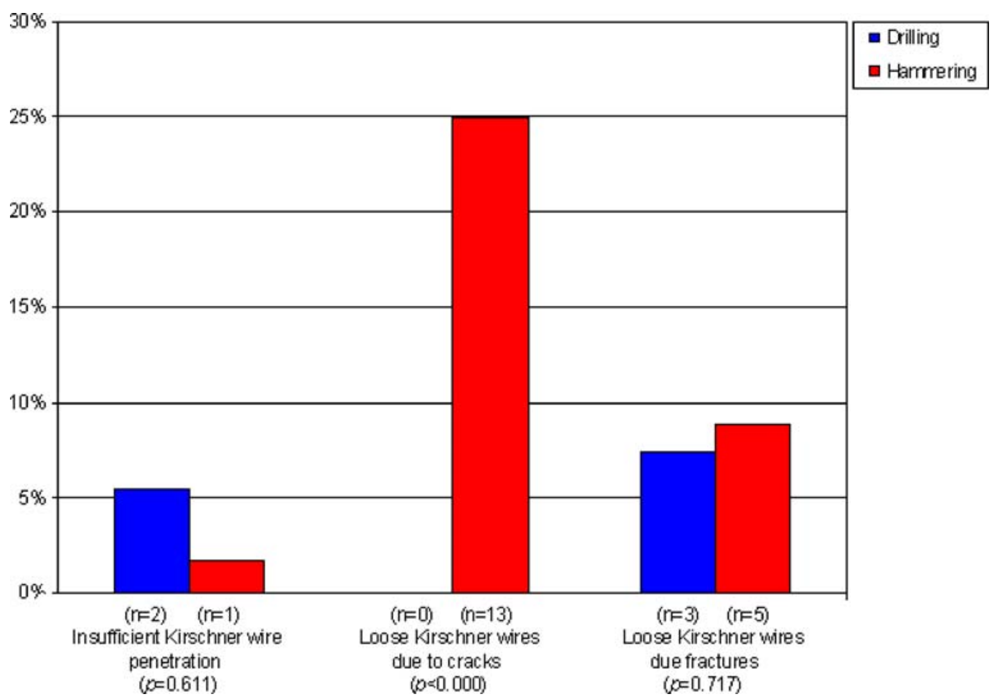

Fig. 3 Percentage of excluded measurements for hammered and drilled Kirschner wires

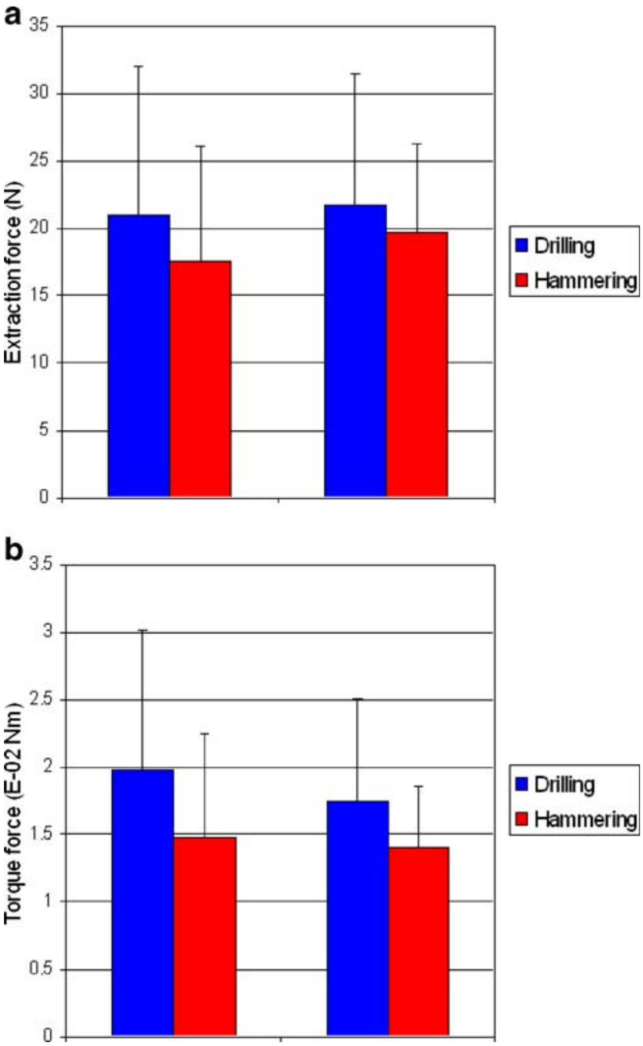

Fig. 4 **a** *N* Newton. Mean values and standard deviations are denoted by *boxes* and *error bars*, respectively. p=0.374 at t=0 and p=0.722 at t=4. **b** *Nm* Newton meter. Mean values and standard deviations are denoted by *boxes* and *error* bars, respectively. p=0.113 at t=0 and p=0.516 at t=4

Table 1 Drilled Kirschner wires: extraction force

Article	Animal model	K-wire Ø (mm)	Drilling speed (rpm)	Extraction force (N)
Present results	Rabbit femur/tibia	0.6	1,200 (t=0)	21.0±11.0
			1,200 (t=4)	21.8±9.7
Wassenaar et al. [24]	Pig ribs	1.25	600	57.4±25.0
Rubel et al. [27]	Bovine femur	2.0	NA	37.7±13.6
Namba et al. [20]	Canine metacarpals	1.57	800	45.8±24.5
			400	113.30±36.9
Graebe et al. [11]	Canine metacarpals	1.57	400	77.8±37.3
			200	148.0±27.2
Zohman et al. [28]	Canine metacarpals	1.57	215	137.8±20.6

NA not available, *N* Newton, *rpm* revolutions per minute

vivo, extraction and torque forces are equal for hammered and drilled K-wires. The same equipment was used in a previous study, but during this experiment, the insertion force was increased during K-wire insertion [24]. We think, however, that the contrast is due to the models used, pig ribs vs rabbit limbs.

On the other hand, the present study shows a significantly shorter insertion time when K-wires were hammered. This is in agreement with previous in vitro results of Wassenaar et al. [24] and Zegunis et al. [26]. It must be stated, however, that drilling time in the present experiment was relatively long compared to that of studies mentioned above. We found that the use of a weight greater than 1.0 kg when hammering K-wires causes an unacceptable amount of bone damage. Despite the low 1.0-kg weight, cracks occurred more frequently when K-wires were hammered. This was unexpected because collagen of human and rabbit bone tissue are comparable [2, 22] and other studies comparing K-wires with different osteosynthesis material also using the rabbit as a model never mentioned cracks or fractures [3, 5, 19]. An exception was the paper of Zegunis et al. In this report, it was advised to lower the power produced by the pneumatic hammer in fragile and small bones to prevent fractures [26]. Our results confirm this advice by demonstrating that a low weight of 1.0 kg is still sufficient to cause cracks. To optimize comparability of hammering and drilling in the present study, a low insertion force weight of 1.5 kg was chosen for drilling, resulting in longer drilling insertion times [6].

Drilling and hammering were both associated with fractures during the first-day follow-up period. The limbs operated on were not immobilized as would be the case in humans [25]. Stress on the operated limb could not be avoided. This caused the rabbits to use their operated limb freely immediately postoperatively, causing fractures and exclusions from further analysis.

In summary, this is the first study to compare drilling and hammering of K-wires in vivo. Both techniques result in equal extraction and torque forces. Hammering results in significantly reduced insertion times but is associated with increased occurrence of cracks. Based on these results, neither of these methods can be identified as a superior technique to insert K-wires in fragile bones.

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